ABERRATION-CORRECTED HRTEM AND THE TEAM PROJECT

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Advanced electron microscopes give us unprecedented views of materials and their unusual behavior on the nanoscale. It is possible to observe how a nanocrystal grows or melts or changes its structure atom by atom, or to investigate the structure of nanocrystals embedded in microcrystals. However, until now, electron microscopes have remained myopic, limited by lens aberrations. As it becomes possible to overcome this limitation with aberration correcting optics, a broad range of new possibilities for research and discovery by high resolution imaging opens up.

Fig. 1 shows the evolution of microscope resolution over time, following Rose [1]. About 50 years ago, electron microscopes began to fill the growing need for high resolution imaging after light microscopes reached the diffraction limit. The ultimate performance of electron microscopes has been limited, until recently, by lens aberrations to about 100 times the electron wavelength λ. Aberration correction can surpass this limitation and improve instrument resolution, contrast and sensitivity significantly, creating the opportunity to directly observe the atomic-scale order, electronic structure, and dynamics of individual nanoscale structures. To take advantage of this opportunity, the TEAM project (Transmission Electron Aberration-corrected Microscope) brings together several microscopy groups in a collaborative effort to jointly design and construct a new generation microscope with extraordinary capabilities. Led by the National Center for Electron Microscopy (NCEM), the effort involves several Department of Energy Laboratories and two commercial partners (FEI and CEOS). The project is part of DOE’s 20-year roadmap of Facilities for the Future of Science [2], and after its completion in 2009, the instrument will be made available to the scientific user community at the National Center for Electron Microscopy.

In his famous 1959 lecture entitled *"There is Plenty of Room at the Bottom"*, Richard Feynman said: *"It would be very easy to make an analysis of any complicated chemical substance; all one would have to do would be to look at it and see where the atoms are. The only trouble is that the electron microscope is one hundred times too poor…. Is there no way to make the electron microscope more powerful?”*

The TEAM project aims at meeting Feynman's challenge by providing a sample space for electron scattering experiments in a tunable electron optical environment to remove some of the constraints that have limited electron microscopy until now. The resulting improvements in spatial, spectral and temporal resolution, the increased space around the sample, and the possibility of exotic electron-optical settings will enable new types of experiments. The TEAM microscope will feature unique corrector elements for spherical and chromatic aberrations, a novel AFM-inspired specimen stage, a high-brightness gun and numerous other innovations that will extend resolution down to the half-Angstrom level. The improvement in sensitivity, brightness, signal to noise and stability will make it possible to address major challenges such as single atom spectroscopy and atomic resolution tomography.

Overall, the most important scientific driving force for improved atomic resolution imaging is the need for in-situ experiments to observe directly the relationship between structure and properties of individual nanoscale objects. Aberration-corrected high resolution electron microscopy (HRTEM) will make it possible to operate the microscope in new experimental configurations. One example of such a new operating mode is the negative-Cs condition used to image oxygen in oxides [3]. Other examples include novel approaches to electron tomography or the combination of Cs correction with a phase plate for phase contrast imaging. Such new modes of imaging are of particular interest in the growing area of interdisciplinary research at the interface between hard and soft matter.

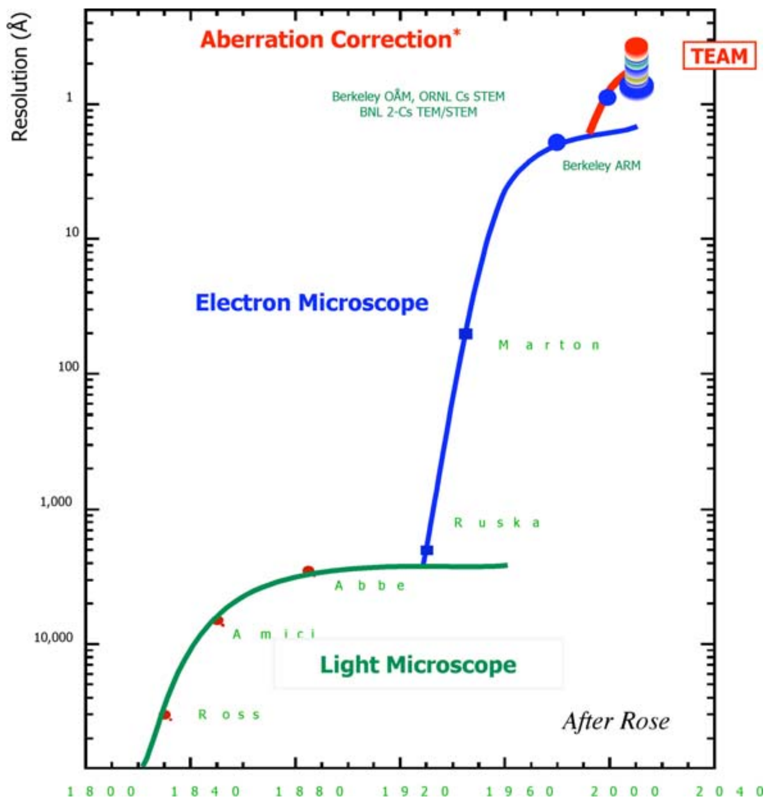

Figure 1. Evolution of resolution in microscopy – after Rose [1].

This talk will highlight some recent discoveries in nanoscale materials science using HRTEM and dynamic observations. It will be shown that nanocrystals come in magic sizes and display a fascinating range of behaviors that get stranger with smaller size. Examples of such materials research will include observations of the relationship between particle size and melting point, the direct measurement of the mechanism and rate of Brownian motion of liquid inclusions inside a solid matrix, and the critical need for 3D tomography to understand the shape and unique behavior of precipitates at grain boundaries in solids. To understand this behavior is important for strong alloys, efficient catalysts, energy-saving devices and the many interesting applications of nanoscience [4].

References

[1] H. Rose, *private communication*

[2] http://www.er.doe.gov/about/Future/Facilities for the Future of Science.htm

[3] C.L. Jia and K. Urban, Science 303, 2001 (2004)

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